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Late Quaternary glacial episodes and sea level changes in the northeastern Billefjorden region, Central Spitsbergen

ABSTRACT: Within the sequence of marine and glacial sediments from the northeastern Billefjorden region, Central Spitsbergen, five glacial episodes are distinguished. Two of them are referred to the Late Pleistocene: the older, about 87 ka, which remains unnamed, and the younger, about 40–56 ka, which is named the Petuniabukta-Adolfbukta Stage and correlated with the Billefjorden Stage from the Kapp Ekholm section. The other three glacial episodes are referred to the Holocene: the oldest, about 8–9 ka (and named the Ebbadalen-Thomsondalen Stage), the middle, probably about 2–3 ka, and the youngest, correlated with the Little Ice Age. The mollusc fauna (11 species) is described from the Holocene marine and glacial sediments; its composition proves Arctic and Boreal climatic conditions with Lusitanian influences.

INTRODUCTION

The paper presents the Late Quaternary glacial episodes and sea level changes in the northeastern Billefjorden region in Central Spitsbergen on the basis of radiocarbon and thermoluminescence datings, supported by the analysis of marine mollusc shells. The glacial episodes in the Billefjorden region have been previously recognized only further to the south in the Kapp Ekholm section (BOULTON 1979, MANGERUD & SALVIGSEN 1984).

The northeastern Billefjorden region embraces shores of Petuniabukta and Adolfbukta (*see* Text-fig. 1) with Ebbadalen, Wordiekammen and the northern forefield of the Nordenskiöld Glacier (*Nordenskiöldbreen*). This area has recently supplied new data on the Late Quaternary glacial episodes in Central Spitsbergen (KŁYSZ 1983a, b, 1985). The fieldworks were performed in summer 1984 during the first expedition of the Quaternary Research Institute, A. Mickiewicz University of Poznań. The collected data allowed to recognize four glacial episodes in this region (KASPRZAK & *al.* 1985). The first one is referred to the Pleistocene and due to its maximum extent in the whole studied area, named the Petuniabukta-Adolfbukta Stage (KŁYSZ & *al.* 1989). Three younger episodes are connected with the Holocene. The oldest is defined the

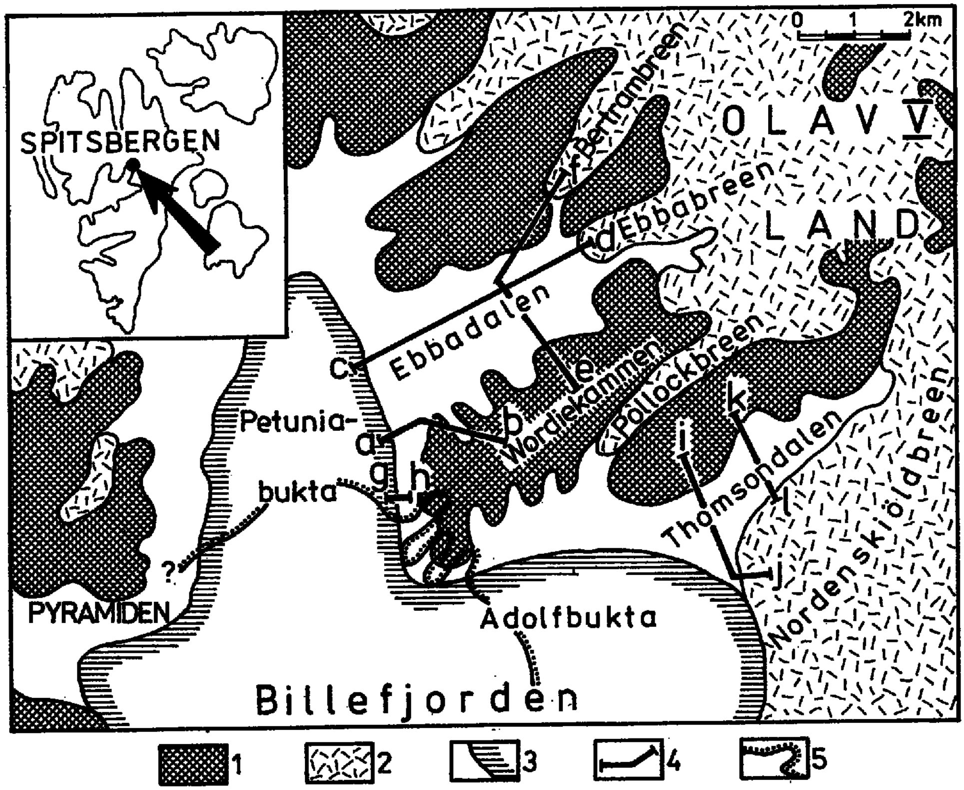


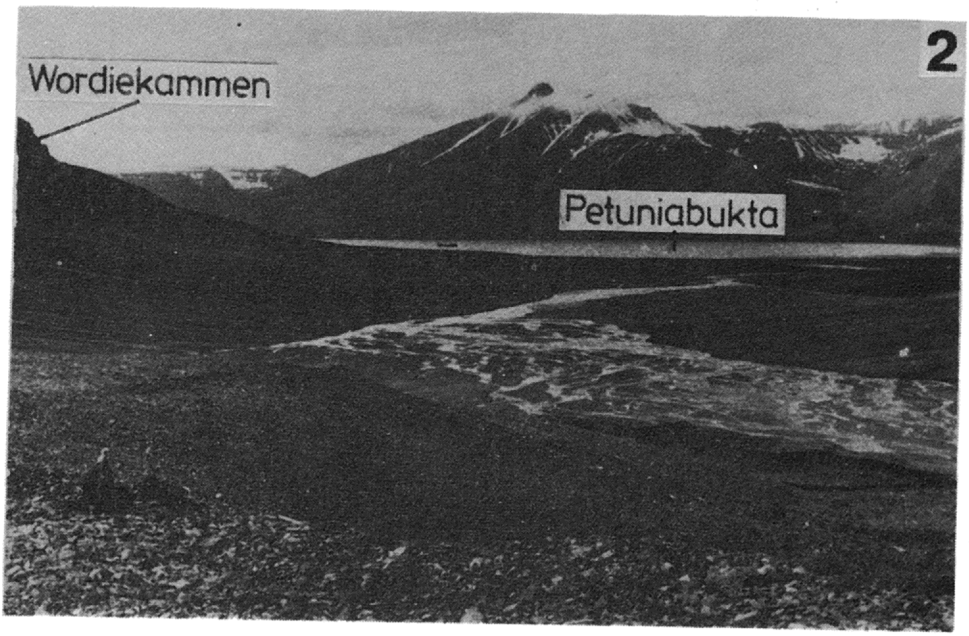
Fig. 1. Location sketch of the northeastern Billefjorden region in Central Spitsbergen
1 — mountains, 2 — glaciers, 3 — sea shoreline, 4 — geologic sections, 5 — glacier extents during the Petuniabukta and Adolfbukta stages

Ebbadalen Stage in Ebbadalen and the Thomsondalen Stage in the forefield of the Nordenskiöld Glacier. The middle episode is correlated with the Late Holocene, and the youngest one with the Little Ice Age.

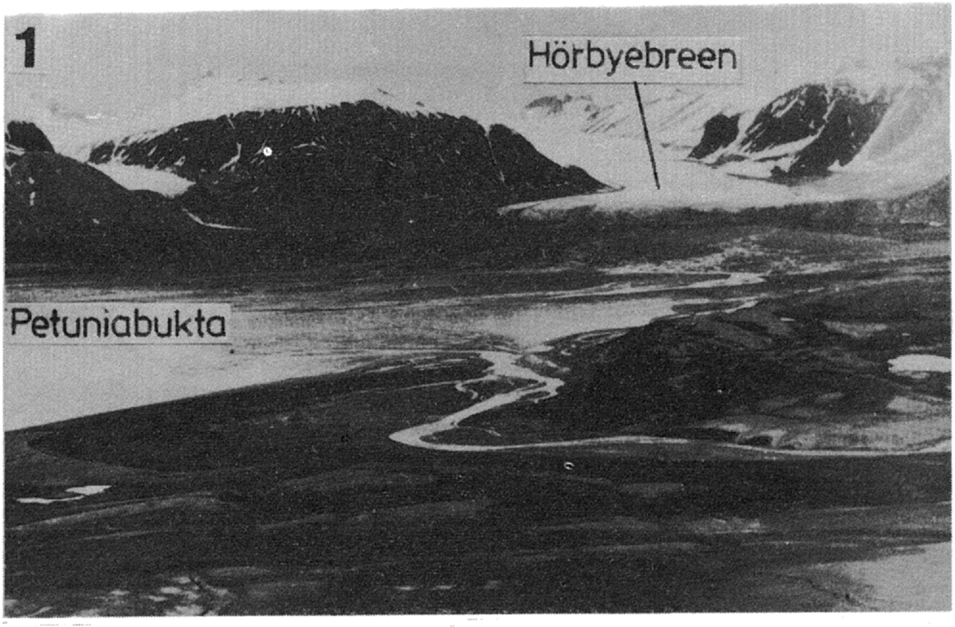
Geomorphologic-geologic mapping of Quaternary landforms and sediments in the studied area (KŁYSZ & *al.* 1987) made up the basis for further subdivision of these episodes into several shorter phases, indicated by trimlines and moraines on mountain slopes, by glacier-derived edges of raised marine beaches and rows of glacial erratics (KŁYSZ & *al.* 1988b, 1989).

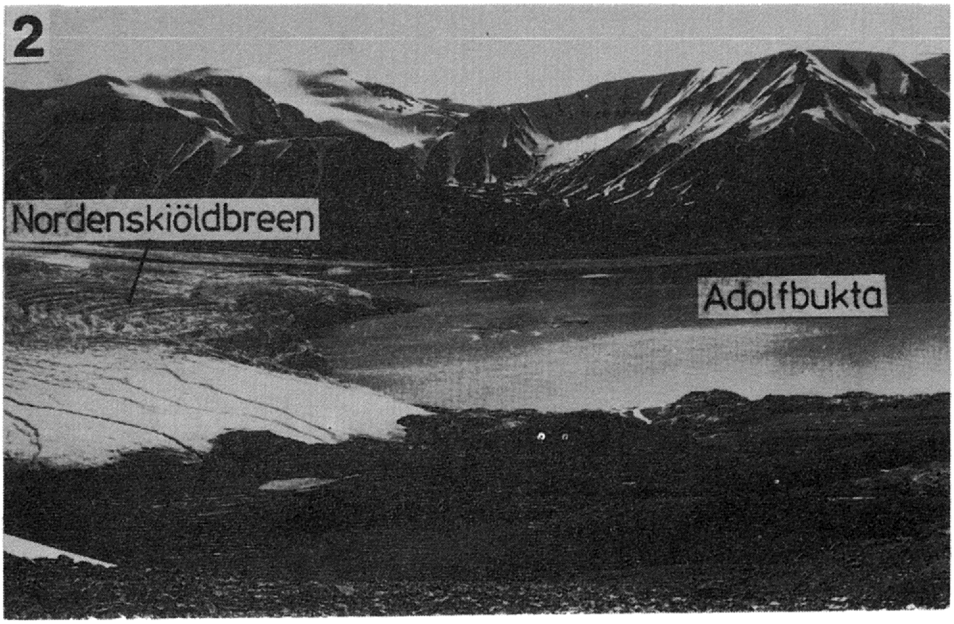
METHODS

During the fieldworks in this area several sections (*A-N*) of Quaternary sediments were analyzed (KŁYSZ & *al.* 1988a, b, 1989) and samples of marine mollusc shells were collected for their paleontologic recognition and radiocarbon dating. These samples came from exposures *A*, *B* and *G* (Text-figs 3—4 and 8) located in Ebbadalen, from the exposure *K* in the forefield of the



1 – Ebba Glacier (*Ebbabreen*) in the eastern part of Ebbadalen; July 1984
2 – Outwash plain in the forefield of the Ebba Glacier; July 1984





1 – Mouth of Ebbaelva in Petuniabukta; July 1984

2 – Ice cliff of the Nordenskiöld Glacier (*Nordenskiöldbreen*) in Adolfbukta, view from the north; July 1984

Nordenskiöld Glacier (Text-figs 7–8) and from a till exposed near Hoglandvatnet (*HV* in Table 1), *i.e.* the area previously described by MARKS & WYSOKIŃSKI (1986).

Studies of subfossil molluscs of the Petuniabukta Region as well as of the other shores of Billefjorden, were previously carried through by FEYLING-HANSSEN (1955) who presented a stratigraphic subdivision of the Late Glacial and Holocene marine sediments in this area. The mentioned exposures were sampled irregularly: 3 samples (*A*1, *A*2 and *A*3) came from the exposure *A* whereas single samples were collected in the exposures *B*, *G*, *K* and *HV*. This sampling method

Table 1

Occurrence of mollusc shells in exposures and samples

Taxons	Exposure and sample symbol						
	A1	A2	A3	B	G	K	HV
GASTROPODA:							
Littorina littorea (LINNAEUS)	+	+		+			
Lepeta coeca (O. F. MÜLLER)			+				
Margarites groenlandicus (GMELIN)			+				
BIVALVIA:							
Mytilus edulis LINNAEUS		+	+	+			
Chlamys islandicus (O. F. MÜLLER)	+			+	+		
Astarte borealis SCHUMACHER							+
Astarte montagui (DILLWYN)	+	+	+	+			+
Macoma calcarea (GMELIN)	+		+		+	+	
Ciliatocardium ciliatum (FABRICIUS) (?)	+						
Mya truncata LINNAEUS	+		+		+	+	+
Hiatella arctica (LINNAEUS)	+		+	+	+	+	+

suggests that samples contained random numbers of specimens as well as of taxons. The shells were generally worn and/or broken but there were also quite numerous complete or only slightly damaged shells. The best preserved ones belong to *Mya truncata* and *Macoma calcarea* from tills of exposures *G* and *K* what indicates that such fauna occurs there in a primary deposit. Shells of *Astarte montagui* and *Hiatella arctica* coming from marine sediments of exposures *A* and *B* were also well preserved.

The whole analyzed shell material contains in total 11 mollusc species (3 gastropods and 8 bivalves). The most commom and most numerous forms (Table 1) are such ones as *Mya truncata* noted in 5 samples from marine sediments and a till, *Hiatella arctica* in 6 samples, *Astarte montagui* in samples of marine sediments from the exposures *A* and *B*.

The thermoluminescence datings, as compared with the radiocarbon ones, give considerably different values for some lithostratigraphic units (Tables 2-3, Text-figs 3–4 and 7). Radiocarbon dates were performed by Ass.-Professor M. F. PAZDUR of the Radiocarbon Laboratory, Institute of Physics of the Silesian Technical University at Gliwice, with a use of methodology described by GOSLAR & PAZDUR (1985). Results of these datings cover the interval from 9740 ± 80 BP to 4780 ± 90 BP. This fact if compared with considerably varying hypsometric location of the analyzed samples (*cf.* Text-fig. 6; *cf.* BLAKE 1960), puts the question of a probable incomplete exchange of carbon isotopes or, possibly, of a dating of the time when aragonite inverted into

Table 2

Radiocarbon dates of mollusc shells

Location	Exposure & sample no.	Age (BP)	Lab. dating no.	Site information	Species
Ebbadalen	A1	8920±50	Gd-3180	till	*Mya truncata*
Ebbadalen	A2	7440±60	Gd-1898	shingle, beach 12–15m	*Mytilus edulis*
Ebbadalen	A3	7630±150	Gd-2396	shingle, beach 12–15m	*Astarte montagui*
Ebbadalen	B	5060±90 4780±90	Gd-2393 Gd-2394	shingle, beach 5–8m	*Astarte montagui* *Mytilus edulis*
Ebbadalen	G	8820±160	Gd-2395	till	*Mya truncata*
Thomsondalen	K	9740±80	Gd-1901	till	*Mya truncata*
Hoglandvatnet	HV	8120±60	Gd-1900	till	*Mya truncata* *Astarte montagui*

calcite. An increased infiltration of carbonate solutions within the more permeable calcite structure (*cf.* MANGERUD 1985) should be also taken into account. These two possibilities seem to be actual as in the analyzed area there are vast exposures of easily weathered carbonate rocks of Carboniferous-Permian age. The authors also noted quite common carbonate precipitates on bottom surfaces of smaller and larger rock pieces and marine shingle of alluvial and talus cones as well as marine beaches. If shells have been contaminated due to the isotope exchange with media that contained less radiocarbon, then the coefficient $\delta^{13}C$ changes and indicates a degree of contamination. When this value is below -3%, the contamination is highly probable (MANGERUD 1972, GOSLAR & PAZDUR 1985).

Effect of the apparent age of shells is to be also taken into account. It arises from a difference between contents of radiocarbon in the atmosphere and in land vegetation, and the one in carbon dioxide and hydrocarbonates dissolved in water. In the case of surface waters of the Atlantic Ocean the apparent age varies from 320 to 520 years whereas at larger depths it can reach 800–1120 years (BROECKER & *al.* 1960, OLSSON 1980, GOSLAR & PAZDUR 1985).

Some difference results probably also from a varying species content of the radiocarbon dated shells. In the samples *A1*, *G*, *K* and *HV*, shells of *Mya truncata* were radiocarbon dated whereas *Astarte montagui* was in samples *A3* , *B* and *HV*, and *Mytilus edulis* in samples *A2* and *B* (cf. Table 2).

Thermoluminescence datings of samples from the studied area were done by Dr. J. BUTRYM of the Thermoluminescence Laboratory, Institute of Earth Sciences of the M. Curie-Skłodowska University at Lublin, in agreement with the methodology there applied (BUTRYM & *al.* 1987). All the samples indicated a very weak TL effect what insisted an increased, even 100 times, sensitivity of the TL analyzer. Low TL level was due to small content of quartz and large of dark minerals in the samples. Much too short transport of deposits (slopes of Wordiekammen and De Geerfjellet are composed of Carboniferous-Permian rocks) could result in preservation of some previous TL component. According to J. BUTRYM (*pers. inf.*) some of the presented TL dates correspond to the time when weathering waste developed on mountain slopes rather than to the final deposition of material in the sampling sites. The dates (Table 3) group the lowest possible values; the highest ones (considered by J. BUTRYM to be wrong) were over a million years and therefore, proved significant mixing of ancient (Carboniferous-Permian) and younger material.

In spite of the presented limitations but basing on geomorphologic and geologic criteria, and in connection with observations in the Billefjorden Region by FEYLING-HANSSEN (1955, 1965), MANGERUD & SALVIGSEN (1984) and SALVIGSEN (1984), the authors refer the age of deposits dated by radiocarbon and TL methods to radiocarbon scale whereas that of older deposits dated by TL method only, to a TL scale (*cf.* Text-fig. 8).

Table 3
Thermoluminescence dates

Location	Exposure	Age (ka)	Lab. dating no.	Site information
Ebbadalen	A	28±4	Lub-918	till
Ebbadalen	A	19±3	Lub-917	shingle, beach 12–15m
Ebbadalen	A	18±3	Lub-916	shingle, beach 12–15m
Ebbadalen	B	17±2.5	Lub-919	shingle, beach 5–8m
Ebbadalen	C	63±9	Lub-922	shingle, beach 40–44m
Ebbadalen	C	55±8	Lub-921	shingle, beach 40–44m
Ebbadalen	C	52±8	Lub-920	till
Ebbadalen	E	23±3	Lub-928	till
Ebbadalen	F	55±8	Lub-923	till
Ebbadalen	G	19±3	Lub-924	till
Ebbadalen	H	22±3	Lub-925	shingle, beach 12–15m
Ebbadalen	J	13±2	Lub-926	till
Ebbadalen	J	15±2.5	Lub-927	till
Thomsondalen	K	66±10	Lub-931	till
Thomsondalen	K	57±8	Lub-930	glaciofluvial gravel
Thomsondalen	K	19±3	Lub-929	till
De Geerfjellet	L	87±13	Lub-932	till
Wordiekammen	M	66±9	Lub-1140	marine shingle
Wordiekammen	M	47±7	Lub-1139	till
Wordiekammen	N	119±17	Lub-1144	lake sand and silt
Wordiekammen	N	53±7	Lub-1143	till
Wordiekammen	N	423±63	Lub-1142	slope sediments
Wordiekammen	N	45±6	Lub-1141	soliflucted till

QUATERNARY BEDROCK

The Quaternary bedrock in the eastern part of the described region is composed of the Late Precambrian metamorphosed carbonate rocks and tillites of the lower Hecla Hoek Formation (HJELLE & LAURITZEN 1982). Nunataks within the Nordenskiöld Glacier composed of these rocks, frequently contain granite dikes K/Ar dated at 420–405 Ma (GAYER & *al.* 1966).

In the central part of the area rocks of the Hecla Hoek Formation are unconformably covered with clastic rocks of the Lower Carboniferous (dipping several degrees westwards), containing inserts of hard coal. They pass upwards into carbonate and sandstone-conglomerate rocks of Upper Carboniferous and Permian age (HJELLE & LAURITZEN 1982) at Wordiekammen, Hultberget, Lövehovden and summits of De Geerfjellet. In Ebbadalen, these rocks are cut by north-south faults, related to the Billefjorden Fault Zone (HARLAND & *al.* 1974).

GEOLOGIC AND GEOMORPHOLOGIC SETTING

The northeastern Billefjorden region is composed of three separate key areas, featured by different sediments and landforms. In Ebbadalen there are mainly glacial forms, considerably accompanied by marine ones (Pl. 1 and Pl. 2, Fig. 1). The forefield of the Nordenskiöld Glacier is occupied almost exclusively by glacial forms (Pl. 2, Fig. 2), whereas in the Wordiekammen area there are mostly slope sediments and, at the shore only, patches of marine deposits (KŁYSZ & *al.* 1987, 1988b, 1989).

EBBADALEN AREA

The downstream part of Ebbadalen is occupied by raised marine beaches 40–45, 30–35, 20–25, 12–15, 5–8, 3–4 and 1–2m a.s.l., cut by a gorge of Ebbaelva. The beach 40–45m a.s.l. forms a steep slope in the east, *i.e.* towards the Ebba Glacier (*Ebbabreen*). Such slope could be formed at a glacier snout. The middle and upstream parts of the valley are mantled with glacial sediments. The valley floor is occupied by a vast and flat sandy outwash plain, being the parent area for air-borne sediments. On southern slope of this part of Ebbadalen there are distinct lateral moraines and several rows of erratics (present also on the glacier-side slope of the beach 40–45m a.s.l.). All they mark previous glacier extents within the valley. In glacial and slope sediments of the middle part of the valley there are occasionally pieces of marine mollusc shells, noted up to about 50m a.s.l. On the southern slope of Ebbadalen there are also two trimlines at 200–300 and 140–200m a.s.l. but gradually lower towards the sea. To the east, the valley is closed by ice-cored moraines, roches moutonnées and the snout of the Ebba Glacier and, moreover, by hanging

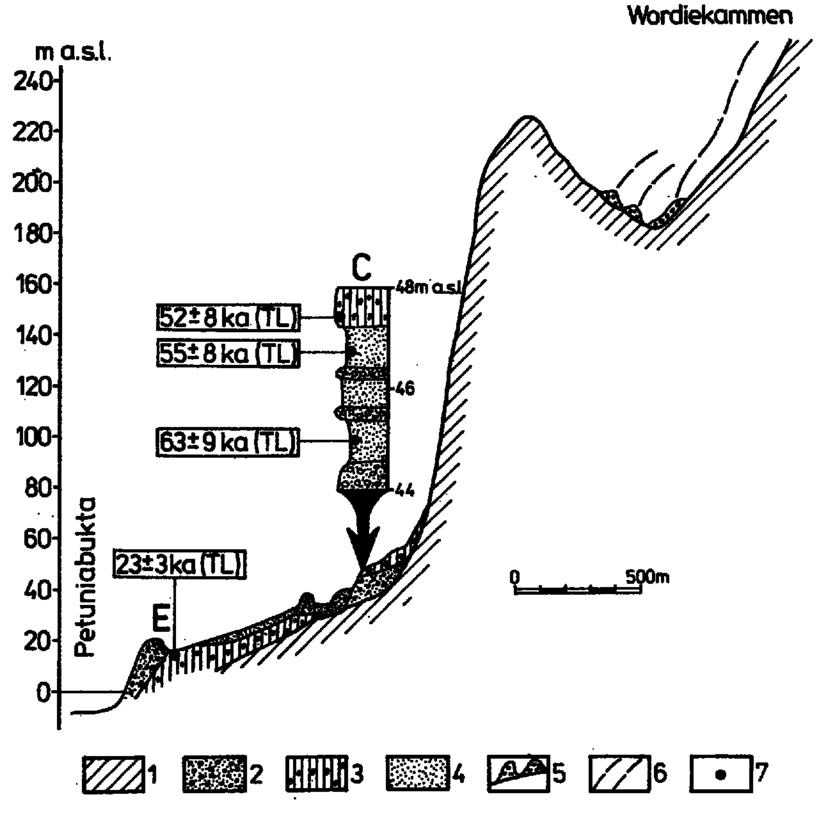
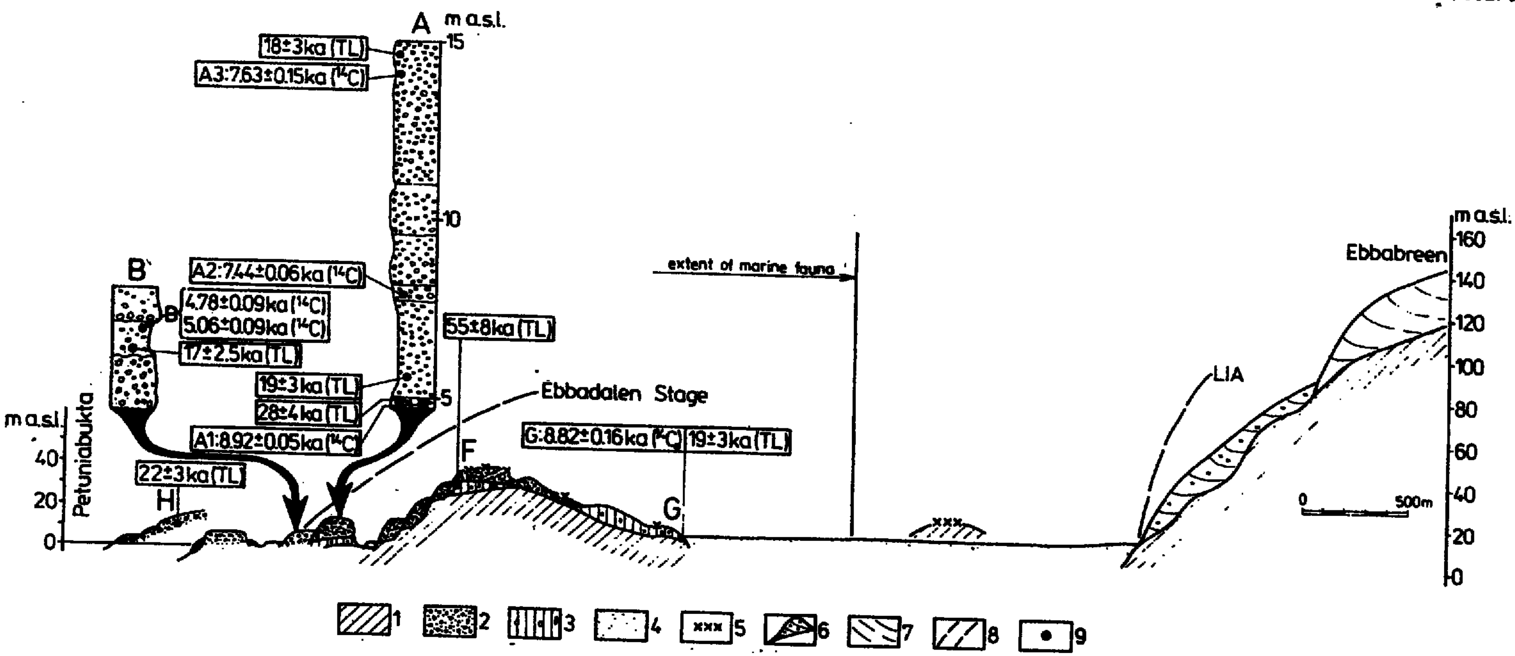


Fig. 2. Geologic section at the northwestern slope of Wordiekammen (*a-b* in Text-fig. 1) with marked exposures (*C*, *E*) and TL dates

1 — bedrock, 2 — marine sands and gravels, 3 — till, 4 — outwash deposits, 5 — deposits of ancient moraines, 6 — glacier extents during the Late Holocene, 7 — sampling sites for TL datings



Geologic section along Ebbadalen (*c-d* in Text-fig. 1) with marked exposures (*A*, *B*, *F*, *G*, *H*), as well as ^{14}C and TL dates

1 — bedrock, 2 — marine sands and gravels, 3 — till, 4 — outwash deposits, 5 — accumulation of large erratics, 6 — deposits of ice-cored moraines, 7 — glacier ice, 8 — glacier extents (LIA — Little Ice Age), 9 — sampling sites for ^{14}C and TL datings

(at about 380m a.s.l.) Bertram Glacier (Bertrambreen). The latter reached the floor of Ebbadalen as indicated by roches moutonnées on northern slopes of the valley as well as lateral moraines and a till at its foot.

The oldest Quaternary sediments in Ebbadalen are the gravels and sands with pieces of marine mollusc shells, noted at the valley outlet at 40–44m a.s.l. and TL dated at 63±9 ka and 55±8 ka (Text-fig. 2). They are covered by a till, TL dated at 52±8 ka, which also forms a substrate of the beach 40–45m a.s.l. in the middle part of the valley where it is TL dated at 55±8 ka. The younger till forms a substrate of the beach 12–15m a.s.l. in the axial part of Ebbadalen (Text-fig. 3) where it is TL dated at 28±4 ka while the embedded shells of *Mya truncata* are radiocarbon dated at 8920±50 BP. This till also forms a surface of the area at a seashore where it is TL dated at 23±3 ka (Text-fig. 2). In the central part of the valley it is TL dated at 19±3 ka and the embedded abundant shells of *Mya truncata* are radiocarbon dated at 8820±160 BP (Text-figs 3 and 4). The mollusc shells form numerous horizontal bands in the exposure *G*. Besides single valves there also occur complete bivalve shells, indicative of their primary deposit (KŁYSZ & *al.* 1989), supposedly of a tanatocoenotic character.

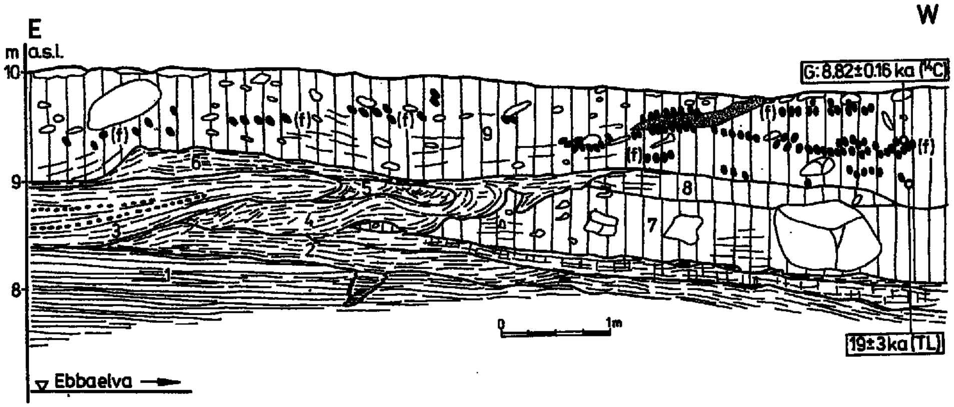


Fig. 4. Exposure (*G* in Text-fig. 3) in Ebbaelva gorge (*after* KŁYSZ & *al.* 1989; *supplemented*) **1** – fine-grained grey-greenish sandstone, poorly consolidated and shaly (140°/12°S), **2** – sandy grey-olive silt, **3** – sandy-clayey silt with sandstone pieces, **4** – yellow-weathered waste of sandstone shale, **5** – rubble of sandstone shale, **6** – fragile, weathered and grey-yellowish sandstone shale, **7** – till, brown and sandy with metamorphic rock pieces, **8** – light-brown till with shale waste, **9** – brown till with numerous boulders and bands of mollusc shells (marked f)

Deposits of the marine beach 12–15m a.s.l. (sands and gravels) are TL dated at 22±3 ka, 19±3 ka and 18±3 ka. The embedded valves of *Mytilus edulis* are radiocarbon dated at 7440±60 BP and those of *Astarte montagui* at 7630±150 BP (Text-fig. 3). Sands and gravels of the marine beach 5–8m a.s.l. are TL dated at 17±2.5 ka and the embedded shell fragments of *Astarte montagui* at 5060±90 BP, whereas those of *Mytilus edulis* at 4780±90 BP by radiocarbon dating (Text-fig. 3).

The till of the Bertram Glacier on a floor of the eastern part of Ebbadalen is TL dated at 13±2 ka and 15±2.5 ka (Text-fig. 5).

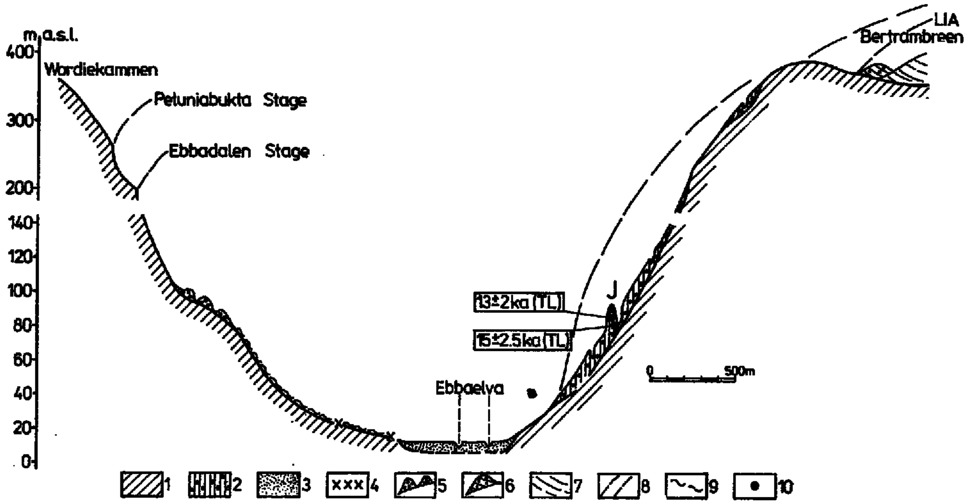


Fig. 5. Geologic section across Ebbaelva (*e-f* in Text-fig. 1) with the marked exposure (*J*) and TL dates

1 — bedrock, 2 — till, 3 — outwash deposits, 4 — accumulation of large erratics, 5 — deposits of ancient moraines, 6 — deposits of ice-cored moraines, 7 — glacial ice, 8 — glacier extents (LIA — Little Ice Age), 9 — slope deposits, 10 — sampling sites for TL datings

WORDIEKAMMEN AREA

The plateau of Wordiekammen seems to have been occupied by an ice cap that mantled everything but nunataks. There are also glacial valleys eroded by several hanging glaciers (to Ebbadalen, near Rudmosepynten and to Adolfbukta) and the small Pollock Glacier (*Pollockbreen*). At foot of the Wordiekammen slopes that reach Petuniabukta and Adolfbukta, there are narrow ledges of marine beaches 70–75, 60–65, 50–55, 40–45, 30–35, 20–25, 12–15, 5–8.

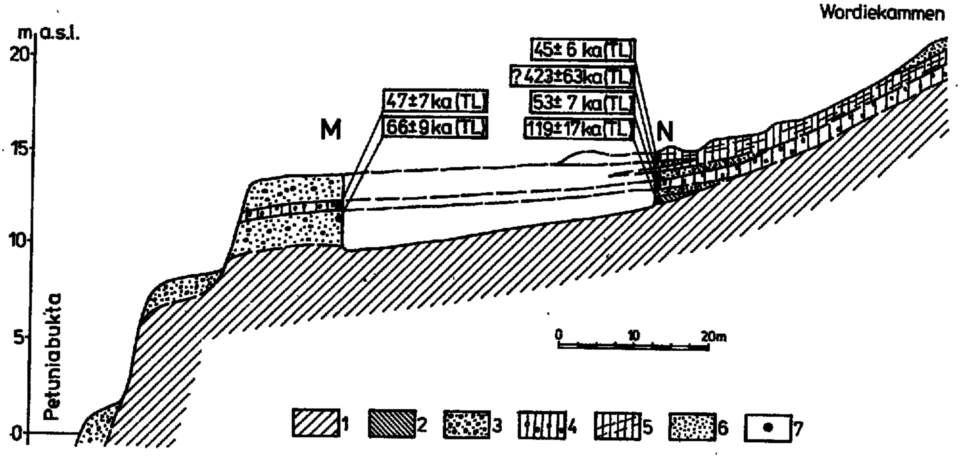


Fig. 6. Geologic section at the foot of the western slope of Wordiekammen (*g-h* in Text-fig. 1) with marked exposures (*M*, *N*) and TL dates (*after* KŁYSZ *& al.* 1988a; *supplemented*)

1 — bedrock, 2 — sands and silts with washed coal streaks, 3 — marine sands and gravels, 4 — till, 5 — solifluted till, 6 — talus rubble, 7 — sampling sites for TL datings

3–4 and 1–2m a.s.l. These beaches are usually considerably mantled with talus cones and, locally, also by gaciofluvial sediments and tills.

On the western slope of Wordiekammen that descends to Petuniabukta (KŁYSZ & *al.* 1988a) the Carboniferous limestones are locally covered by sands and silts containing streaks of washed coal (Text-fig. 8). Their TL dating is 119±17 ka, and they are covered by gravels with pieces of marine mollusc shells, TL dated at 66±9 ka. The overlying till with insert of coal silt and pieces of marine mollusc shells is TL dated at 47–53 ka. The covering gravels with pieces of marine mollusc shells of the beach 12–15m a.s.l. (Text-fig. 6) and containing much slope and redeposited material, are TL dated so suprisingly as at 423±63 ka. On the beach surface there are locally solifluction lobes, composed of an older till that is TL dated at 45±6 ka (Text-fig. 6). It contains numerous interbeds of sands and gravels with pieces of marine mollusc shells.

FOREFIELD OF THE NORDENSKIÖLD GLACIER

The southeastern slope of De Geerfjellet that contacts with the Nordenskiöld Glacier, is mantled by various glacial sediments and landforms. Trimlines that mark previous glacial extents are noted at 500–600, 400–480, 340–420, 280–320, 240–260, 160–200 and 40–70m a.s.l. The slope is locally covered by patches of till, usually overlain by slope sediments. At the foot of De Geerfjellet there is a lateral glacial valley of Thomsonelva that is limited from the glacier side by an ice-cored moraine. In the intramorainal zone there appears a till that forms locally a fluted moraine. This zone is dissected by the lateral outwash train which cuts the ice-cored moraine and captures the upstream reach of Thomsonelva. In a morainal zone of the Nordenskiöld Glacier there are numerous roches moutonnées. A till on the slope of De Geerfjellet at 370m a.s.l. is TL dated at 87±13 ka (Text-fig. 7). In a ravine entering the Thomsondalen at the foot of this massif

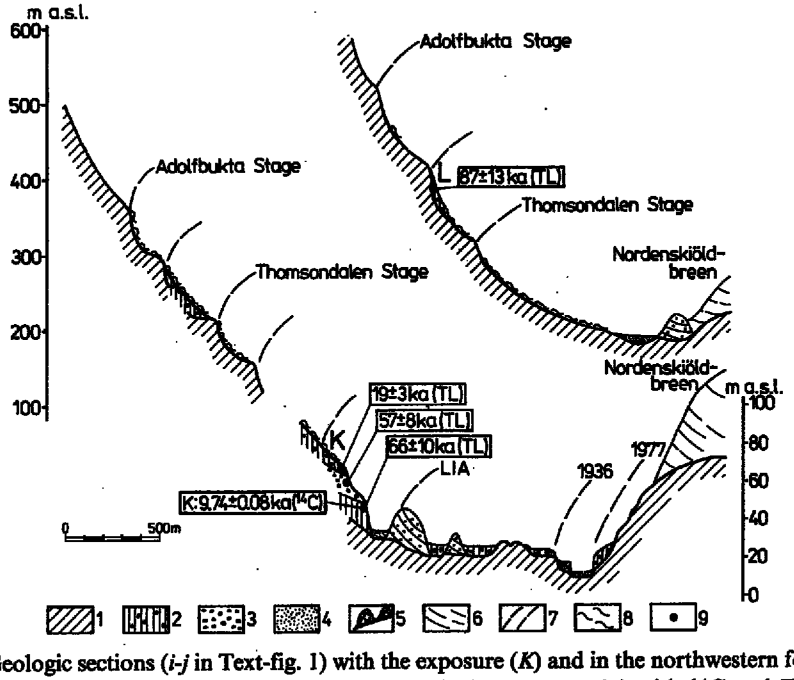
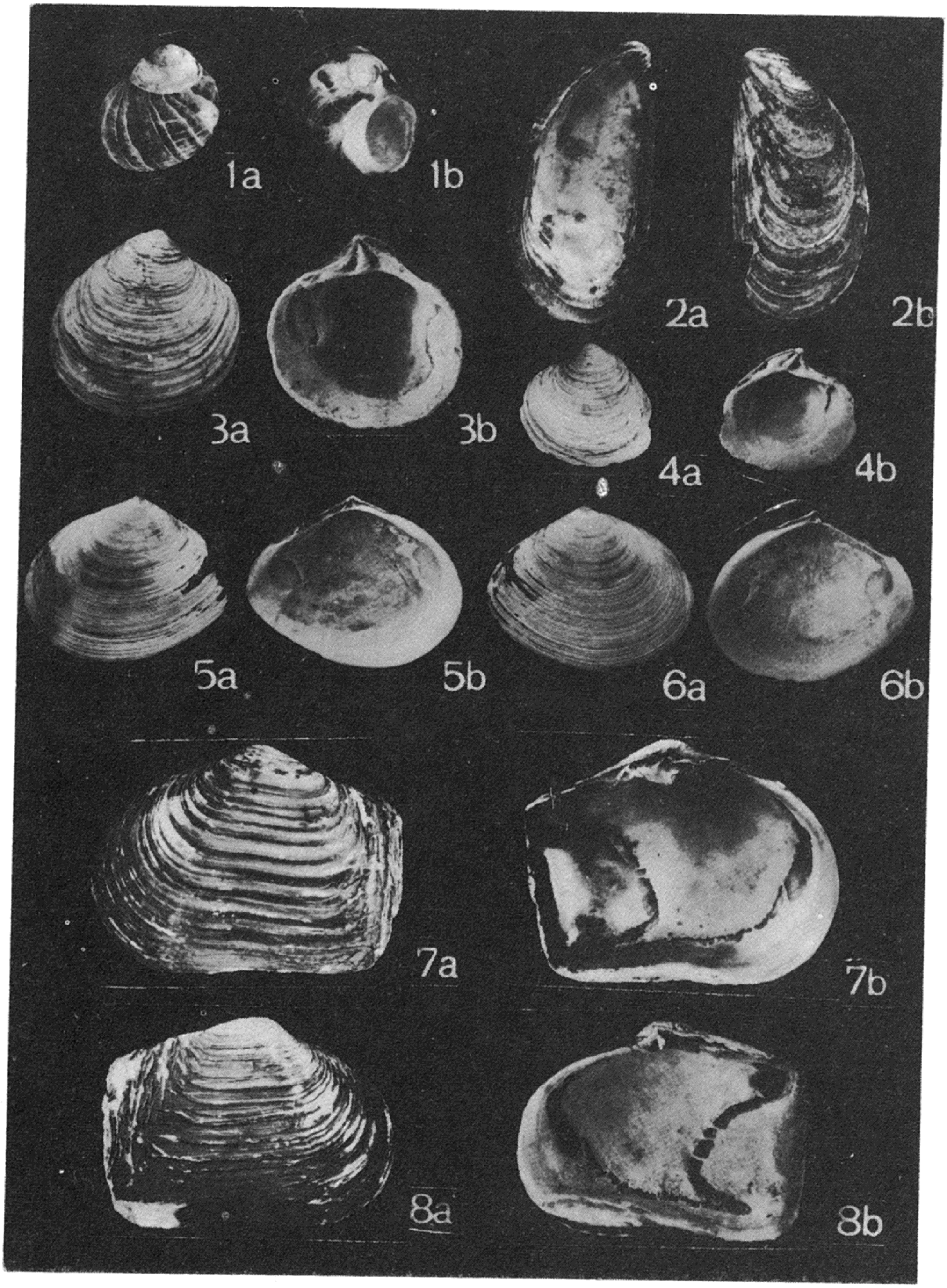


Fig. 7. Geologic sections (*i-j* in Text-fig. 1) with the exposure (*K*) and in the northwestern forefield of the Nordenskiöld Glacier (*k-l* in Text-fig. 1) with the exposure (*L*) with ^{14}C and TL dates 1 – bedrock, 2 – till, 3 – glaciofluvial sands and gravels, 4 – outwash deposits, 5 – deposits of ice-cored moraines, 6 – glacial ice, 7 – glacier extents (LIA – Little Ice Age), 8 – slope deposits, 9 – sampling sites for ^{14}C and TL datings



Mollusc shells from northern Billefjorden, Central Spitsbergen

All photos of natural size; taken by S. KOLANOWSKI

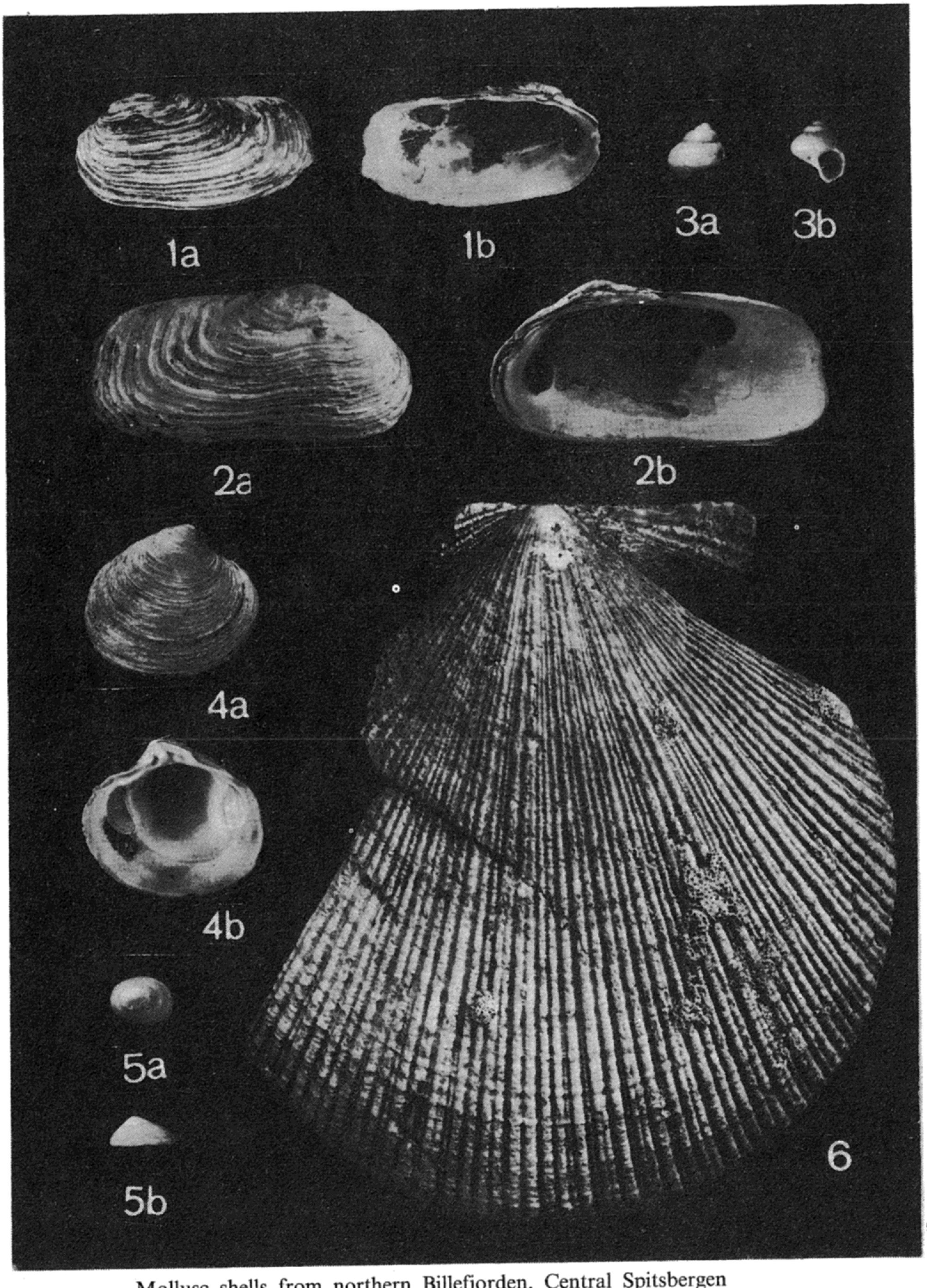
1 – *Littorina littorea* (LINNAEUS); *1b* adapertural, *1b* apertural view

2 – *Mytilus edulis* LINNAEUS; left valve: *2a* inner, *2b* outer view

3-4 – *Astarte montagui* (DILLWYN); *3* right valve, *4* left valve (*3a-4a* outer, *3b-4b* inner views)

5-6 – *Macoma calcarea* (GMELIN); *5* left valve, *6* right valve (*5a-6a* outer, *5b-6b* inner views)

7-8 – *Mya truncata* LINNAEUS; *7* left valve, *8* right valve (*7a-8a* outer, *7b-8b* inner views)



Mollusc shells from northern Billefjorden, Central Spitsbergen

All photos of natural size; taken by S. KOLANOWSKI

1-2 — *Hiatella arctica* (LINNAEUS); *1* left valve, *2* right valve (*1a-2a* outer, *1b-2b* inner views)
3 — *Margarites groenlandicus* (GMELIN); *3a* adapertural, *3b* apertural view
4 — *Astarte montagui* (DILLWYN); right valve: *4a* outer, *4b* inner view
5 — *Lepeta coeca* (O. F. MÜLLER); *5a* top, *5b* side view
6 — *Chlamys islandicus* (O. F. MÜLLER); right valve, outer view

two tills are noted, separated by several meters thick series of glaciofluvial sands and gravels (Text--fig. 7). The lower till is TL dated at 66±10 ka and enclosed shells of *Mya truncata* were radiocarbon dated at 9740±80 BP. The overlying glaciofluvial sediments are TL dated at 57±8 ka and the upper till at 19±3 ka.

FOSSIL FAUNA AND PALEOCLIMATIC CONDITIONS

The collected mollusc fauna is generally poor in species, especially if compared with the fauna that inhabits at present the Svalbard offshores where 164 species of gastropods and bivalves have been noted up to now (RÓŻYCKI 1987, 1988). The previously reported fossil assemblages are considerably richer in species. FEYLING-HANSSEN (1955) listed 28 gastropod species and 23 bivalve species from Quaternary sediments of the Billefjorden region. A modest number of species from the studied area results probably not only from random sampling but also from its location in the innermost part of the fiord, *i.e.* under considerable influence of fresh waters. The recognized species live at present in seas around Spitsbergen, and *Mytilus edulis* is the only exception (RÓŻYCKI 1987, 1988). On the other hand, all the noted species have been found in Quaternary sediments of Spitsbergen (*e.g.* FEYLING-HANSSEN 1955, 1965a, b, c; BIRKENMAJER 1958; FEYLING-HANSSEN & ULLEBERG 1984) and some of them are quite common, as exemplified by *Mya truncata, Hiatella arctica, Astarte montagui, Macoma calcarea* and *Chlamys islandicus* (see Pls 3–4). In the Billefjorden region *Astarte borealis* is a common species, especially in deposits of medium and low marine beaches (FEYLING-HANSSEN 1955, 1965a, b, c) but this fact is not reflected in composition of the studied samples. The species *Lepeta coeca* is rather rare, the same as *Ciliatocardium ciliatum* that was identified by a small shell fragment only. The fauna noted in the analyzed sites forms small assemblages, 3 to 7 species each. They comprise mainly Arctic and Boreal molluscs. Some of them reach the Lusitanian zone or are cosmopolitan, as *e.g. Hiatella arctica.*

The list of individual assemblages after their present zoogeographic distribution is based on a subdivision used by FEYLING-HANSSEN (1955), and it enables to distinguish two separate groups. The first one is composed of molluscs from exposures *A* and *B*. Generally, these molluscs could occur in the lower Arctic to Boreal or lower Arctic to middle Boreal zone, thus under climatic conditions which were more favorable than the present ones in this area. This group is characteristic of the occurrence of *Littorina littorea* and *Mytilus edulis* which are absent in the second group. Both these species were considered by FEYLING-HANSSEN (1955) as key ones for the postglacial climatic optimum. Amongst the assemblages of this group the one from the sample *A1* (till) is especially worth mentioning. It contains the species *Ciliatocardium ciliatum* typical for the lower Arctic, *i.e.* a slightly cooler climate than indicated by other assemblages.

The second group are the molluscs from exposures *G, K* and *HV*, typical of upper Arctic to middle Boreal zoogeographic zones. This group lived under more severe climatic conditions than the first one. Such common species as *Mya truncata, Hiatella arctica* and *Macoma calcarea* were noted by FEYLING-HANSSEN (1955, 1965a, b) in deposits of higher marine beaches of Billefjorden, regarded by him as the Late Glacial and Early Holocene. The sample *HV*, taken at Hoglandvatnet, contains also two other species of the genus *Astarte*. They are typical of lower (*i.e.* younger) marine beaches and are redeposited in sampled sediments.

Water temperature can be calculated on the requirements of the present-day fauna in Spitsbergen seas (RÓŻYCKI 1987). Most species described from the studied area live at temperatures from −0.82 to 3.8° C. The presence of the gastropod *Littorina littorea* and the bivalve *Mytilus edulis* amongst the molluscs of the first group, can displace slightly these limits towards higher temperatures.

Representatives of the described fauna live at present at varying depths beneath the freezing water layer, equal from several to several hundred meters. Most of them live at depths 10−25m (*cf.* FEYLING-HANSSEN 1965a) but descend in some cases to 300−400m or even, as in case of *Hiatella arctica*, to 1400m. The species *Lepeta coeca* is also relatively deep-water as in the Isfjorden Region it does not occur at depths smaller than 20m and has been noted to depths of 100−140m (FEYLING-HANSSEN 1955). The species *Ciliatocardium ciliatum* is more frequently noted below 50m depth. The investigated species have also different requirements of the bottom habitats. Some of them live usually on sandy of silt-sandy sea floor, but *Mya truncata* prefer a clayey bottom (DAVITASHVILI & MERKLIN 1966), and thus it was able to live also on a till floor.

CHRONOSTRATIGRAPHY AND CORRELATIONS

The presented paleoclimatic conclusions as well as ^{14}C and TL dates enable to establish a chronostratigraphic scheme for the northeastern Billefjorden Region in the Late Quaternary (Text-fig. 8).

The oldest are the sands and silts resting on the Carboniferous limestones that form a substrate of the marine beach 12−15m a.s.l. at western foot of Wordiekammen (Text-fig. 6; KŁYSZ & *al.* 1988a). The TL age of these sediments is equal 119±17 ka, and they are referable to the Eemian (?) Interglacial (*cf.* MILLER 1982, FORMAN & MILLER 1984). These sediments can correspond with the sands and gravels resting on the bedrock and under the oldest till in the section Kapp Ekholm (*cf.* BOULTON 1979, MANGERUD & SALVIGSEN 1984), the latter being TL dated at 116 ka (TROITSKY & *al.* 1979).

In the described area the oldest till of the Würm Glaciation (= Sörkapp Land Glaciation = Vistulian; *see* LINDNER & *al.* 1984) occurs probably on the southern slope of De Geerfjellet, TL dated at 87±13 ka (Text-fig. 7). It can correspond with the Early Würm glacial episode distinguished in the section Kapp Ekholm by MANGERUD & SALVIGSEN (1984). In the studied area this till could also be deposited later, during the maximum extent of the Würm glaciers, named the Petuniabukta-Adolfbukta Stage (KŁYSZ & *al.* 1988b, 1989).

The younger warming in the studied area was expressed by the development of smaller glaciers and of three highest marine beaches 70−75, 60−65 and 50−55m a.s.l. (*cf.* SALVIGSEN & ÖSTERHOLM 1982). On the slope of Wordiekammen their sediments are overlain by a till that forms a substrate of the marine beach 12−15m a.s.l., and they are TL dated at 66±9 ka (Text-fig. 6). The corresponding marine sediments in Ebbadalen are dated at 63−55 ka, and they are overlain by a till (Text-fig. 5). This interval is herein named the Older Interstage (Text-fig. 8). In the section Kapp Ekholm this time is represented by interstadial silts, TL dated at 70 ka (TROITSKY & *al.* 1979) and radiocarbon dated as older than 45,400 BP (BOULTON 1979).

The younger glacial episode in the studied area indicated maximum development of glaciers during the Petuniabukta-Adolfbukta Stage (Text-fig. 8; KŁYSZ & *al.* 1988b, 1989). The TL dates of tills of this time at 56–45 ka prove a possible correlation with a till from the section Kapp Ekholm, the age of which was TL defined as older than 47 ka (TROITSKY & *al.* 1979) and radiocarbon dated as older than $46{,}300^{+2100}_{-1700}$ BP (MANGERUD & SALVIGSEN 1984). This till is correlated by MANGERUD & SALVIGSEN (1984) with the Billefjorden Stage as understood by BOULTON (1979).

The successive warming is defined by the authors as the Younger Interstage (Text-fig. 8). In the studied area, similarly as in the whole Isfjorden Region, no

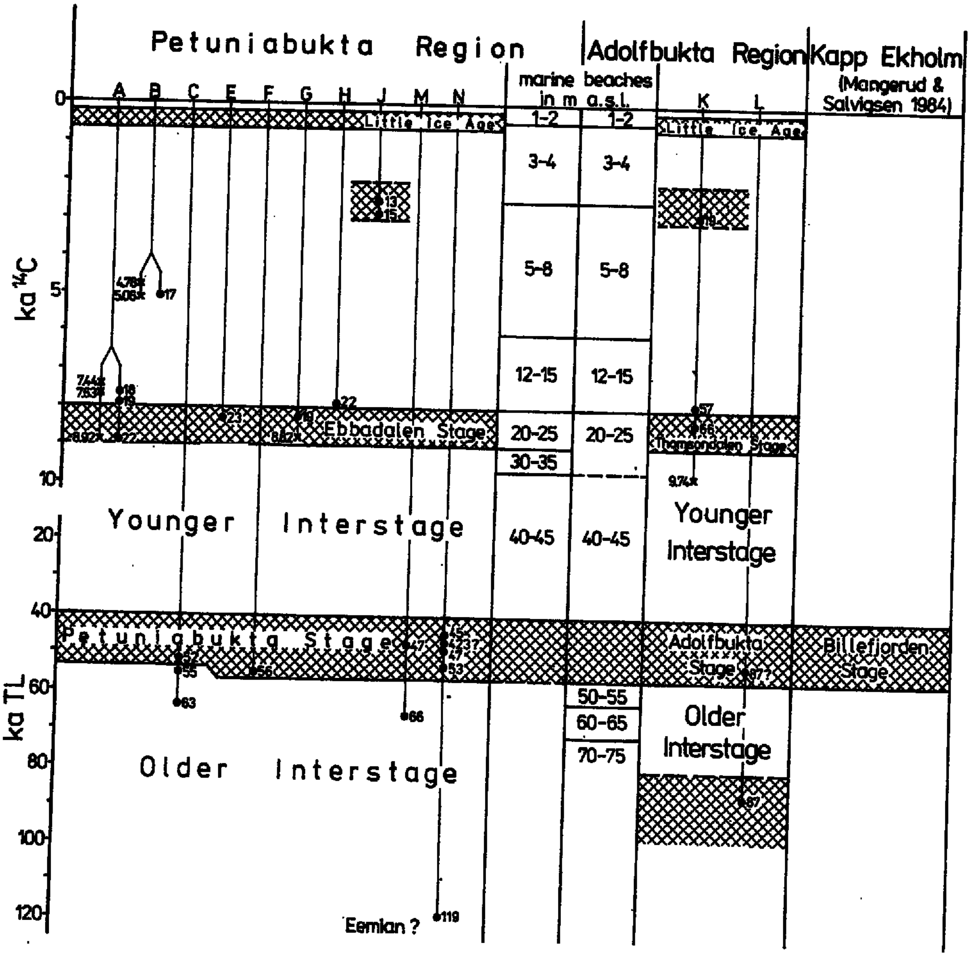


Fig. 8. Age correlation of marine and glacial sediments from the northeastern Billefjorden region with reference to the location of the Billefjorden Stage in the section Kapp Ekholm
A-N – studied exposures (*cf.* Text-figs 2–7); *crosses* – location of radiocarbon-dated mollusc shells, *circles* – sediments dated by TL method; glacial episodes are hachured

glacial sediments of this time were noted (SALVIGSEN & NYDAL 1981, MANGERUD & *al.* 1984a, b). Three marine beaches 40–45, 30–35 and 20–25m a.s.l. were formed in this time (Text-fig. 8). A more widespread extent of the sea in this time than at present is proved by the occurrence of marine mollusc shells in the younger tills. These shells are radiocarbon dated at 9740–8820 BP (Text-figs 6, 7 and 8). Similar age of shells from a till was noted for the Austfjorden Region (MARKS & WYSOKIŃSKI 1986).

The till of the successive glacial episode occurs in Ebbadalen as well as in the forefield of the Nordenskiöld Glacier (Text-figs 3–4 and 8). Confrontation of its TL age and of the radiocarbon dates of enclosed marine mollusc shells yielded unexpected results (Text-fig. 8). The TL age was defined at 23–19 ka in Ebbadalen and 66 ka in the forefield of the Nordenskiöld Glacier. Basing on radiocarbon dates of shells and on correlations with neighboring areas (SALVIGSEN 1981, BOULTON 1979, BOULTON & *al.* 1982, MARKS & WYSOKIŃSKI 1986), the authors regard this till as corresponding to the Early Holocene glacier advance (Text-fig. 8), named the Ebbadalen Stage for the Ebbadalen area, and the Thomsondalen Stage for the forefield of the Nordenskiöld Glacier (KŁYSZ & *al.* 1988b, 1989).

During the Middle Holocene warming, marine sediments of the raised beaches 12–15 and 5–8m a.s.l. were deposited (Text-fig. 3). The marine molluscs preserved in the beach sediments 12–15m a.s.l. in Ebbadalen were radiocarbon dated at 7630–7440 BP, while the sediment itself was TL dated at 18–22 ka (Text-fig. 8). The shells from sediments of the raised beach 5–8m a.s.l. in Ebbadalen were radiocarbon dated at 5060–4780 BP, while that sediment was TL dated at 17 ka (Text-fig. 8).

In the case of the forefield of the Nordenskiöld Glacier the dates of mollusc shells from the lower till (Text-fig. 7) indicate that the younger glaciofluvial sediments are of Middle Holocene age in spite of their TL date equal 57 ± 8 ka (Text-fig. 8). In this way the upper till, TL dated at 19 ± 3 ka (Text-fig. 7), can represent the Late Holocene glacial episode (Text-fig. 4; *cf.* FEYLING-HANSSEN 1965a, KARCZEWSKI & *al.* 1981, FORMAN & *al.* 1987). In Ebbadalen this episode is indicated by a till of the Bertram Glacier (Text-fig. 5), TL dated at 13–15 ka (Text-fig. 8).

The youngest Holocene is connected with deposition of two lowest marine beaches (3–4 and 1–2m a.s.l.) and with a glacial advance during the Little Ice Age (Text-fig. 8).

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PÓŹNOCZWARTORZĘDOWE EPIZODY GLACJALNE I ZMIANY POZIOMU MORZA W PÓŁNOCNOWSCHODNIEJ CZĘŚCI BILLEFJORDU NA SPITSBERGENIE

(Streszczenie)

Na podstawie badań terenowych, oznaczeń malakofauny oraz datowań metodą termoluminescencji i radiowęgla określono zasięg i wiek młodoczwartorzędowych epizodów glacjalnych i zmian poziomu morza w północnowschodniej części Billefjordu* (*patrz* fig. 1—7, tab. 1—3 oraz pl. 1—2). W osadach tego rejonu stwierdzano występowanie szczątków fauny mięczaków morskich (11 gatunków), których zasięg występowania obejmował strefę arktyczną, borealną i luzytańską (*patrz* tab. 1 oraz pl. 3—4).

Spośród wyróżnionych pięciu epizodów glacjalnych, dwa odniesiono do późnego plejstocenu. Starszy epizod miał miejsce około 87 ka, młodszy zaś, nazwany stadium Petuniabukta-Adolfbukta, miał miejsce około 40—56 ka i skorelowany został ze stadium Billefjordu w profilu Kapp Ekholm (*patrz* fig. 8). W holocenie wyróżniono trzy epizody glacjalne: najstarszy został nazwany stadium Ebbadalen-Thomsondalen i nastąpił około 8—9 ka, środkowy miał miejsce zapewne około 2—3 ka, najmłodszy zaś skorelowany został z Małą Epoką Lodową.

Młodoczwartorzędowe zmiany poziomu morza w badanym obszarze wyraziły się utworzeniem systemu 10 podniesionych tarasów morskich (*patrz.* fig. 8). W starszym interstadiale, tj. okresie poprzedzającym stadium Petuniabukta-Adolfbuktą, powstały 3 najwyższe tarasy morskie (70—75, 60—65 oraz 50—55m n.p.m.). W młodszym interstadiale powstały 3 tarasy morskie (40—45, 30—35 oraz 20—25m n.p.m.). Z okresem środkowego i młodszego holocenu związano powstanie 4 najniższych tarasów morskich (12—15, 5—8, 3—4 oraz 1—2m n.p.m.).

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